TARDEC

--- TECHNICAL REPORT ---

No. 21795

Comparison of Energy Loss in Talon Battery Trays: "Penn State" and IBAT

By

Ty Valascho

UNCLASSIFIED: Dist A. Approved for public release

U.S. Army
Tank Automotive Research, Development, and Engineering Center
Detroit Arsenal
Warren, Michigan 48397-5000

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
26 APR 2011	**N/A**	**-**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Comparison of Energy Loss in Talon Battery Trays: Penn State and IBAT	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
Ty Valascho	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
US Army, Tank Automotive Research Development and Engineering Command (TARDEC) Warren, MI 48397	**21795**
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
US Army, Tank Automotive Research Development and Engineering Command (TARDEC) Warren, MI 48397	11. SPONSOR/MONITOR'S REPORT NUMBER(S) **21795**

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES

The views, opinion, and/or findings contained in this report are those of the authors and should not be construed as an Official Department of the Army position, policy, or decision, unless so designated by other documents., The original document contains color images.

14. ABSTRACT

Laboratory testing of two battery tray designs for the QinetiQ NA Talon robot: Talon Battery Box and the Improved Battery Adapter Tray (IBAT). State of Charge (SOC) Loss was measured for each design.

15. SUBJECT TERMS

Talon, robot, battery tray, loss, State of Charge, IBAT, SOC, Battery Box

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**SAR**	**17**	

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. **PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.**			
1. REPORT DATE ***(DD-MM-YYYY)*** 26-04-2011	**2. REPORT TYPE** Technical		**3. DATES COVERED** ***(From - To)*** 31/03/2011 – 25/04/2011
4. TITLE AND SUBTITLE Comparison of Energy Loss in Talon Battery Trays: "Penn State" and IBAT			**5a. CONTRACT NUMBER** **5b. GRANT NUMBER** **5c. PROGRAM ELEMENT NUMBER**
6. AUTHOR(S) Ty Valascho			**5d. PROJECT NUMBER** **5e. TASK NUMBER** **5f. WORK UNIT NUMBER**
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) US Army, Tank Automotive Research Development and Engineering Command (TARDEC) Warren, MI 48397			**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) US Army, Tank Automotive Research Development and Engineering Command (TARDEC) Warren, MI 48397			**10. SPONSOR/MONITOR'S ACRONYM(S)** **11. SPONSOR/MONITOR'S REPORT NUMBER(S)**
12. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited			
13. SUPPLEMENTARY NOTES The views, opinion, and/or findings contained in this report are those of the authors and should not be construed as an Official Department of the Army position, policy, or decision, unless so designated by other documents.			
14. ABSTRACT Laboratory testing of two battery tray designs for the QinetiQ NA Talon robot: Talon Battery Box and the Improved Battery Adapter Tray (IBAT). State of Charge (SOC) Loss was measured for each design.			
15. SUBJECT TERMS Talon, robot, battery tray, loss, State of Charge, IBAT, SOC, Battery Box			
16. SECURITY CLASSIFICATION OF: **UNCLAS DIST A**			**17. LIMITATION OF ABSTRACT** A
a. REPORT DIST A	**b. ABSTRACT** DIST A	**c. THIS PAGE** DIST A	**18. NUMBER OF PAGES** 17
19a. NAME OF RESPONSIBLE PERSON Ty Valascho			
19b. TELEPHONE NUMBER ***(include area code)*** (586) 282-0681			

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

Comparison of Energy Loss in Talon Battery Trays: "Penn State" and IBAT

April 26, 2011

Version 1.1

POC: Ty Valascho

US ARMY TARDEC - Ground Vehicle Robotics (GVR)

ty.valascho@us.army.mil

586.282.0681

Executive Summary

There are currently two battery tray designs for powering the QinetiQ NA Talon robot using BB-2590 Li-Ion batteries. The products are the Battery Box design and the Improved Battery Adapter Tray (IBAT) design. The Battery Box is commonly referred to as the "Penn State" design.

Testing was performed to compare the inherent power loss of both designs when powered and turned on. This testing involved installing 6 fully charged batteries in each design and measuring the State of Charge (SOC) periodically until one battery became completely discharged. SOC is measured from 0 to 100 for each battery and represents the amount of energy stored in it: a fully charged battery has 100 SOC and a fully discharged battery has 0 SOC. In addition, a simultaneous measurement was made of the internal loss of 6 batteries.

The results of the testing show that each battery in a Penn State Battery Box will lose approximately 0.27 SOC per hour. Each battery in an IBAT will lose approximately 0.09 SOC per hour.

Contents

Introduction

Power consumption on small Unmanned Ground Vehicles is of paramount concern as mission lengths increase. To increase energy density, save money, and ease logistical concerns the Army has been moving from proprietary batteries to the standard BB-2590 batteries on small UGVs. A device called a battery tray is required to do this on the TALON robot, a product of QinetiQ North America.

Background

There are currently two different designs for TALON battery tray, the Battery Box and the Improved Battery Adapter Tray (IBAT). Both fit in the same package space within a Talon and provide electrical power to the robot.

The Battery Box was designed by the Applied Research Laboratory (ARL) at Pennsylvania State University through funding from the US Navy. It is commonly called the "Penn State" design. A photograph is provided in Figure 1. The battery covers are not shown in this image.

Figure 1 – "Penn State" Battery Box

The IBAT was designed by ARTEC EOD at Picatinny Arsenal, New Jersey and is shown in Figure 2. There are top covers that attach to the Velcro straps which are not show in this image.

Figure 2 – IBAT Battery Tray

Both systems use between two and six BB-2590 Li-Ion rechargeable batteries to power the TALON robot. The BB-2590 is a re-chargeable Lithium Ion battery used extensively within the US Department of Defense to power small electronics, such as communications devices. It contains about 6.8 Amp·Hours of energy at a 24 Volts (DC) / 2 Amp discharge rate. Figure 3 contains an image of the device, showing the "top side" with the power connector and SMBus pin-pads.

Figure 3 – A BB-2590 Lithium Ion Re-chargeable Battery

The purpose of this test was to measure and compare the amount of energy loss that each battery tray design has when powered on, but the robot it is connected to is powered off.

The amount of loss measured this way indicates how long the batteries can be left in a stowed position between missions without recharging or replacing the batteries.

Energy Loss

When a battery tray is powered on, it is using some energy to keep the internal electronics and external displays powered. Energy is being consumed even when the robot it is connected to is off and not consuming power. This consumed energy is the energy loss – commonly shortened to just "loss" – of the system and represents the slow but steady drip of power that is reducing the available energy in the batteries all the time.

All electrical systems have some loss, including cell phones and laptops. Sleep modes – such as when the hard drive or display is powered down when not in use - are ways that loss is commonly reduced in consumer electronics. Currently fielded robots have no sleep mode – they are either completely on or completely off.

State of Charge (SOC)

To measure and compare the loss, the concept of State of Charge (SOC) must be explained. SOC is a percentage of available energy left in a battery. When the battery is fully charged, it has 100 SOC. When the battery is completely discharged, it has 0 SOC.

Measurement of SOC

SOC cannot be measured directly. It can be calculated, however, and this can be done a number of different ways. Most methods for calculating SOC, such as "Coulomb counting" utilize a mathematical model of the battery and the measurement of voltage and current over time.

The BB-2590 battery itself keeps track of its SOC, which can be queried over the SMBus interface on the battery. The Penn State design reads and displays the SOC of each battery installed. This measurement and display was utilized for this testing.

Methodology

To measure the loss in a battery tray, 6 fully charged batteries were used for each tray design. The SOC of each battery was measured before the test, and then installed in the tray. Each tray was left powered on, but not connected to a robot. The SOC of every battery was measured periodically until one of the batteries reached zero SOC.

Test Configuration

All tests were performed indoors at 25^{o} C. Three preliminary tests were also conducted, and the results are provided in Note that these values are for the tray and are with respect to the total SOC of the tray, which can have a value between 0 and 600.

Each battery in the tray is going to lose roughly 1/6 of this value per hour of use, in addition to whatever the robot is consuming. If the values are then normalized on a “per battery” basis, the results are

Penn State Battery Box 0.27 Individual Battery SOC loss per hour

IBAT Battery Tray: 0.09 Individual Battery SOC loss per hour

Appendix A. The results from the 3 preliminary tests were found to be consistent with the final test.

The testing consisted of three test configurations: 6 batteries in an IBAT, 6 batteries in a Penn State battery box, and 6 batteries unconnected to a tray. The purpose of the six "No Tray" batteries was to measure the internal loss of the batteries themselves.

Battery Numbers

The Penn State design clearly labels the battery numbers for reference, printed on the top of the product. The IBAT has no such label, so the same relative position was used for numbering the IBAT batteries, as shown in Figure 4.

Figure 4 – Battery Numbering Scheme

The "No Tray" batteries were arbitrarily numbered.

Table 1 provides the serial numbers of all components used during this test.

Table 1 – Component Serial Numbers used in Test

	Penn State Batt Box S/N: 1846		IBAT S/N: 0502		No Tray	
Batt #	Batt Mfr Date	Batt S/N	Batt Mfr Date	Batt S/N	Batt Mfr Date	Batt S/N
1	1208	A035625	0307	A01795	1208	A035620
2	0210	A018068	0210	A018154	1210	A018022
3	0109	A036545	0210	A018145	0608	A020660
4	0507	011825	1208	A035621	0708	A021195
5	0109	A036844	0608	A020697	0210	A018165
6	0907	A06120	0606	A1438	0407	A03231

Results

The testing was performed from April 11, 2011 at 8:28 until April 25, 2011 at 7:48. The SOC values of the six batteries in each test configuration were measured, then summed to give a single number that represents the complete SOC of all six batteries, called "Total Tray SOC." This number goes from a value of 600 for a completely charged pack of six batteries to a value of 0 when all six batteries are completed depleted.

The summarized results of the testing are shown in Table 2, and the complete set of test data are provided in Appendix B. After the initial measurement, the SOC values were measured 11 more times during the complete 2 week test.

Table 2 – Total Tray SOC Loss Comparison Results

Time (Hours)	Penn State Total Tray SOC	IBAT Total Tray SOC	"No Tray" Total Tray SOC
0	586.0	578.0	576.0
23	547.0	570.0	575.0
47	502.0	557.0	573.0
71	454.0	539	572
98	401	523	571
167	285	480	568
191	249.0	473	568
216	210	455	565
241	172	446	564
262	140	435	564
286	103	424	561
335	33	390	560

These same results are provided graphically in Figure 5, which shows clear trends for the Total Tray SOC loss.

Figure 5 – Comparison of Total Tray SOC Loss over Time

From the data, the battery tray loss over time appears to be linear. Calculation of the approximate SOC loss per hour of operation for the two designs was performed using the following formula:

$$SOC\_loss\_per\_hour = \frac{Total\_Tray\_SOC_{Start} - Total\_Tray\_SOC_{End}}{Total\_Test\_Hours} - No\_Tray\_SOC\_loss\_per\_hour$$

The calculation of $No\_Tray\_SOC\_loss\_per\_hour$ is defined as

$$No\_Tray\_SOC\_loss\_per\_hour = \frac{No\_Tray\_Total\_Tray\_SOC_{Start} - No\_Tray\_Total\_Tray\_SOC_{End}}{Total\_Test\_Hours}$$

Using these two formulas yields the following results:

Penn State Battery Box: 1.60 Total Tray SOC loss per hour

IBAT Battery Tray: 0.51 Total Tray SOC loss per hour

Note that these values are for the tray and are with respect to the total SOC of the tray, which can have a value between 0 and 600.

Each battery in the tray is going to lose roughly 1/6 of this value per hour of use, in addition to whatever the robot is consuming. If the values are then normalized on a “per battery” basis, the results are

Penn State Battery Box 0.27 Individual Battery SOC loss per hour

IBAT Battery Tray: 0.09 Individual Battery SOC loss per hour

Appendix A

Test A

Because the Penn State battery tray requires pins 7 (Loop In) and 8 (Loop Out) be connected for the battery tray to be turned on, the first round of testing was performed by putting the Penn State tray in a TALON robot which was turned off. The IBAT was left on a table. Both battery trays were left on. This test was performed indoors at 25^{o} C.

Test A was run from March 31, 2011 at 16:32 until April 4, 2011 at 6:59 – a total of 86.5 hours. The data from this testing are provided in Table 3 and Table 4.

Table 3 – Test A Penn State SOC Testing Results

Penn State S/N: 1846 Batt #	Initial SOC	End SOC	Difference (Total Loss)
1	99	70	29
2	99	69	30
3	99	67	32
4	99	66	33
5	99	69	30
6	99	75	24
Total	*594*	*416*	*178*

Table 4 – Test A IBAT SOC Testing Results

IBAT S/N: 0502 Batt #	Initial SOC	End SOC	Difference (Total Loss)
1	99	95	4
2	91	85	6
3	99	93	6
4	97	94	3
5	99	95	4
6	97	85	12
Total	*582*	*547*	*35*

From Test A, it can be determined that the approximate SOC loss / hour of operation for each tray is:

Penn State Battery Box: 2.06 SOC loss / hour

IBAT Battery Tray: 0.40 SOC loss / hour

Note that measurement of SOC for both products is consistent, since measurement for both devices was made by the Penn State product, but it is unknown how accurate these measurements are. It is likely the Penn State tray is getting its SOC information from the battery itself over the SMBus interface.

Test B

The second test was performed with both trays on a table and a jumper wire put between pins 7 and 8 on the Penn State tray. Both battery trays were left on. This test was performed indoors at 25° C.

Test B was conducted by putting both battery trays on a table with no robot at all. This test was performed from April 4, 2011 through April 7, 2011. SOC data were collected every day, and are provided in Table 5 and Table 6.

Table 5 - Test B Penn State SOC Testing Results

Penn State S/N: 1846 Batt #	Initial SOC	Measured at Hour 15.4	Measured at Hour 39.1	Measured at Hour 63.3
1	99	93	85	77
2	93	90	83	76
3	99	98	90	82
4	89	81	73	65
5	99	95	87	79
6	99	97	93	86
Total Tray SOC	*578*	*554*	*511*	*465*

Table 6 – Test B IBAT SOC Testing Results

IBAT S/N: 0502 Batt #	Initial SOC	Measured at Hour 15.4	Measured at Hour 39.1	Measured at Hour 63.3
1	99	99	99	95
2	97	98	97	97
3	99	99	98	94
4	99	99	97	93
5	95	93	91	89
6	95	93	91	89
Total Tray SOC	*584*	*581*	*573*	*557*

These data are graphed in Figure 6.

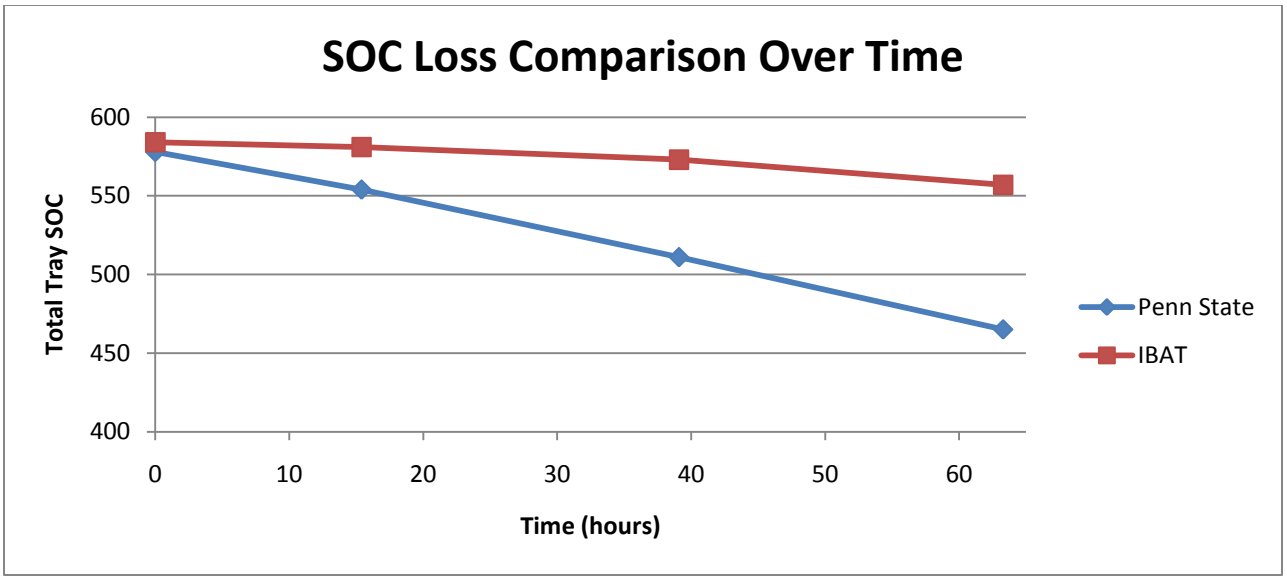

Figure 6 – Penn State Vs. IBAT Loss Comparison over time

Test C

The third test was conducted using only the Penn State battery tray. This test was performed indoors at 25° C.

The Penn State battery tray was left on a table, but turned off. In addition, 6 batteries were measured that were not connected to a battery tray. This was intended to measure the loss from the batteries themselves, which also have some electronics in them.

The data from the unpowered Penn State tray and no battery tray testing are provided in Table 7 and

Table 8.

Table 7 - Test C Penn State SOC Testing Results

Penn State S/N: 1846 Batt #	Initial SOC	End SOC	Difference (Total Loss)
1	98	98	0
2	98	97	1
3	99	99	0
4	99	99	0
5	99	99	0
6	97	96	1
Total	590	588	2

Table 8 - Test C SOC Testing Results with No Battery Tray

No Battery Tray Batt #	Initial SOC	End SOC	Difference (Total Loss)
1	94	93	1
2	99	99	0
3	99	99	0
4	89	88	1
5	95	95	0
6	98	98	0
Total	574	572	2

This test was run from April 7, 2011 at 7:39 until April 11, 2011 at 7:50. The total test time was 96.2 hours, which yields the following calculation of the approximate SOC loss / hour of operation for Test 3:

Penn State Battery Box, powered off: 0.02 SOC loss / hour

No Battery Tray: 0.02 SOC loss / hour

Based on these results it is very likely that the Penn State battery tray has no loss when powered off, as the small amount of loss that was measured is probably due to the loss in the batteries themselves.

Appendix B

The complete set of test measurement data for all three test configurations in the final test are provided in this Appendix.

Table 9, Table 10, and Table 11 provide the complete set of State of Charge measurements made during the 2-week battery tray loss testing.

Table 9 – Penn State Complete Test Measurements

Date→	4/11/2011	4/12/2011	4/13/2011	4/14/2011	4/15/2011	4/18/2011	4/19/2011	4/20/2011	4/21/2011	4/22/2011	4/23/2011	4/25/2011
Time→	8:28	7:46	7:36	7:29	10:50	7:50	7:35	8:26	9:20	6:48	6:25	7:48
Batt #	SOC	SOC	SOC	SOC	SOC	SOC	SOC	SOC	SOC	SOC	SOC	SOC
1	99	92	84	76	67	49	43	36	30	24	18	6
2	99	95	87	79	71	50	44	38	32	26	20	7
3	99	96	91	83	74	54	48	41	35	30	23	11
4	99	92	84	76	67	50	44	37	31	26	20	8
5	92	82	74	66	57	38	32	26	19	14	8	0
6	98	90	82	74	65	44	38	32	25	20	14	1

Table 10 – IBAT Complete Test Measurements

Date→	4/11/2011	4/12/2011	4/13/2011	4/14/2011	4/15/2011	4/18/2011	4/19/2011	4/20/2011	4/21/2011	4/22/2011	4/23/2011	4/25/2011
Time→	8:28	7:46	7:36	7:29	10:50	7:50	7:35	8:26	9:20	6:48	6:25	7:48
Batt #	SOC	SOC	SOC	SOC	SOC	SOC	SOC	SOC	SOC	SOC	SOC	SOC
1	98	94	90	87	84	76	73	71	68	66	63	57
2	98	97	95	93	91	87	87	86	86	85	84	80
3	99	97	94	90	86	79	77	74	72	71	68	61
4	96	96	93	90	85	75	72	69	66	64	61	53
5	99	99	99	95	95	85	87	80	80	75	75	70
6	88	87	86	84	82	78	77	75	74	74	73	69

Table 11 – "No Tray" Complete Test Measurements

Date→	4/11/2011	4/12/2011	4/13/2011	4/14/2011	4/15/2011	4/18/2011	4/19/2011	4/20/2011	4/21/2011	4/22/2011	4/23/2011	4/25/2011
Time→	8:28	7:46	7:36	7:29	10:50	7:50	7:35	8:26	9:20	6:48	6:25	7:48
Batt #	SOC	SOC	SOC	SOC	SOC	SOC	SOC	SOC	SOC	SOC	SOC	SOC
1	90	89	89	89	88	87	87	87	86	86	86	85
2	99	99	99	98	98	98	98	97	97	97	96	96
3	96	96	95	95	95	94	94	93	93	93	92	92
4	98	98	98	98	98	98	98	98	98	98	98	98
5	99	99	99	99	99	99	99	99	99	99	99	99
6	94	94	93	93	93	92	92	91	91	91	90	90

The columns show the data measurements at the specific hour during the test in which they were taken. These points in time represent "snapshots" of the SOC of the six batteries in each cradle.